CHANGES IN WATER AVAILABILITY AND DEMAND WITHIN SOUTH AFRICA'S SHARED RIVER BASINS AS DETERMINANTS OF REGIONAL SOCIAL AND ECOLOGICAL RESILIENCE

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ABSTRACT

South African water use patterns in four river basins shared with neighbouring states have reached the point where there is little additional water available for new water uses. Population growth and new developments will aggravate this situation. Rural situations in these basins have both a formal and informal water economy with those in the informal water economy the most vulnerable and least influential. Water shortages have different effects on urban and rural communities and shape the social resilience and adaptive coping capacity of these communities. The imbalance in social resilience between rural and urban communities must be accounted for when water resource managers make trade-offs between equity, efficiency and sustainability objectives at different scales. Properly informed decisions need to be made and acted upon to sustain and strengthen social resilience in these river basins.

KEYWORDS

Transboundary rivers; water scarcity; socio-economic development; resilience, vulnerability; Incomati; Limpopo; Maputo; Orange-Senqu.

INTRODUCTION

South Africa shares six river basins (Incomati, Limpopo, Maputo, Orange-Senqu, Thukela and Umbeluzi) with six neighbouring countries (Botswana, Lesotho, Mozambique, Namibia, Swaziland and Zimbabwe). The water available in four of these river systems – the Incomati, Limpopo, Maputo and Orange-Senqu basins (**Figure 1**) – is under enormous pressure from existing demands for water in South Africa and in the neighbouring states (Ashton *et al*., 2006; Turton *et al*., 2006).

Pressures on these shared river systems will increase as each country seeks to develop its economy and provide water for urban and rural residents. Further pressures are added as South Africa strives to redress the inequities imposed by previous political dispensations (Turton, 2003). A large proportion of South Africa's population and its industrial, mining, power generation and agricultural activities are located in the four shared river basins and underpin the local, national and regional economies. These basins are approaching "closure" (Turton and Ashton, 2008) as insufficient water is available for new developments if current water use patterns continue unchanged. The fifth and sixth shared river basins – the Thukela and Umbeluzi basins (**Figure 1**) – are also heavily developed but their water resources have not yet reached the levels of stress experienced in the other four basins (Ashton and Turton, 2008, in press).

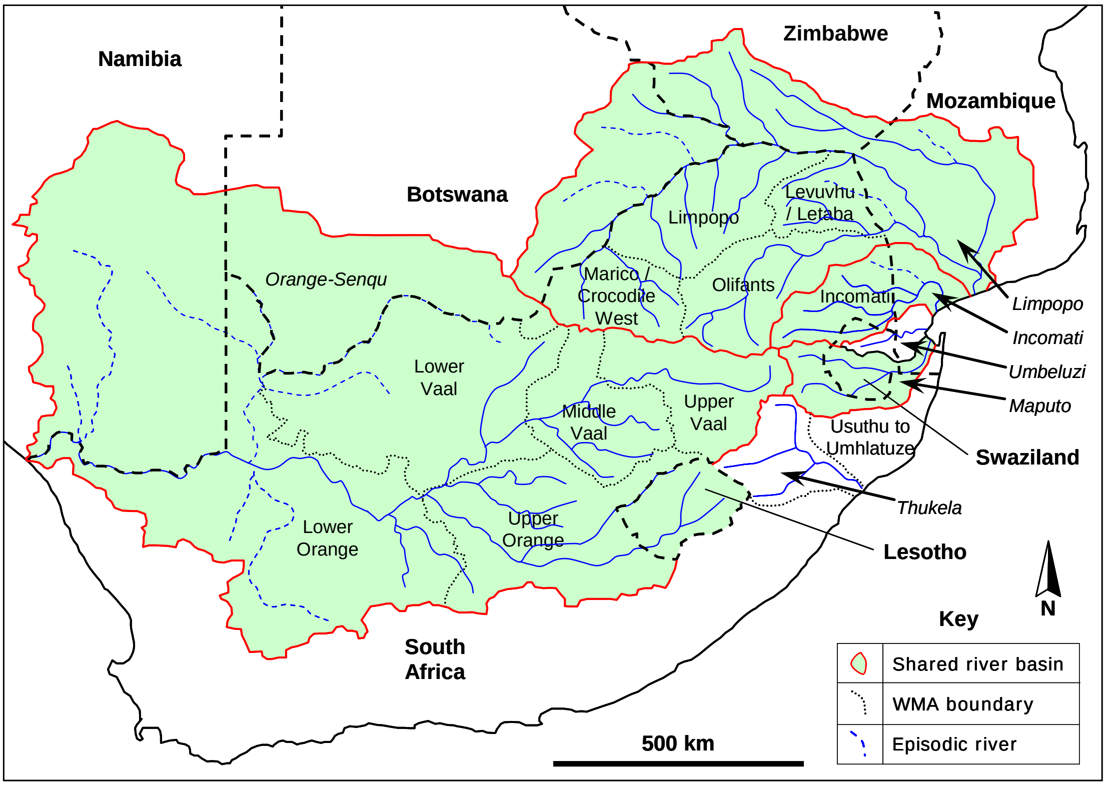

Figure 1. Map of southern Africa, showing the six river basins that South Africa shares, their South African Water Management Areas, and the main rivers and tributaries in each basin. The four shared basins examined in this study are shaded.

The extent to which South Africa has exploited the water resources of the four shared basins has led to debate and even controversy amongst representatives of government departments and the wider public – both locally and within the neighbouring states. Several investigators (e.g. Mohamed, 2003; Turton, 2003) have reported that some residents of the neighbouring countries resent the fact that South Africa already uses a large (and therefore possibly inequitable) portion of the water resources in the shared river basins. This is perceived to disadvantage the social and economic development aspirations of these countries and indicates stress on social resilience (Langridge *et al.*, 2006). In each river basin, the socio-economic and ecological systems are interdependent, and rely heavily on the accessibility, availability and reliability of supplies of good quality water. In developing countries, people – particularly those in rural settings - have limited access to social services that support resilience. They are thus particularly vulnerable when stresses such as diminished access to potable water arise, and declining social resilience in rural areas will drive increased urban migration. Each basin can therefore be viewed as an example of a complex social-ecological system (SES), comprising sub-systems operating at different scales from national to rural and urban, and connected through their demands for and use of water.

In this study we examine the availability of water resources in the South African segments of the four shared river basins, and the current and projected future patterns of demand for water, as determinants of resilience to growing water stresses within these SESs. We then consider the implications of local (i.e. basin-specific) and wider regional water shortages and how these shape the array of adaptive political, social, economic and technological responses – the self-organizing actions expected of resilient SESs - to current and potential future demands for water in these basins.

RESEARCH APPROACH ADOPTED

This study is based on a desk-top analysis of the existing information for four shared river basins - the Incomati, Limpopo, Maputo and Orange-Senqu systems. Projected values for future water availability were derived from Department of Water Affairs and Forestry (DWAF) reports on planned measures to provide increased water to particular sectors of the economy in the eleven water management areas forming these basins (Basson *et al*., 1997; DWAF, 1997; DWAF, 2003a - k). South Africa has a total of nineteen Water Management Areas (WMAs), each of which will be managed by a Catchment Management Agency (CMA; DWAF, 1997). Projected patterns of water use in the year 2025 were based on population estimates for the year 2000 (STATS-SA, 2007), adjusted by using DWAF estimates of low (1.1%) and high (2.2%) rates of annual potential population growth.

While no specific allowance was made for the possible future implications of HIV/AIDS on water use (DWAF, 2003a – k), the pandemic will likely reduce population growth rates and influence water use patterns (Ashton and Ramasar, 2002; Rascher *et al*., 2008, in press). In South Africa, approximately 5.5 million people (18.8% of the total adult population) are either HIV-positive or have AIDS; similar high adult HIV prevalence rates characterize South Africa's neighbours (UNAIDS, 2006). Each person with HIV/AIDS requires higher than average quantities of clean water for personal hygiene to cope with opportunistic infections (Kamminga and Schuringa, 2005).

Current estimates suggest that there may be between 3 and 5 million unregistered or "illegal" immigrants in South Africa (STATS-SA, 2007). However, as most of these individuals appear to have subsistence lifestyles, they seldom exert a significant additional demand on the water used in formal sectors of the South African economy. Therefore, their water consumption was estimated on the DWAF basic "lifeline level" of 25 litres per person per day (DWAF, 1997). Importantly, people with subsistence lifestyles seldom have access to effective sanitation and waste disposal systems and many of their activities have adverse – though usually localized – impacts on the quality of water in nearby water resources (Pallett, 1997).

Data on water use and water availability in each water management area in South Africa's shared river basins were obtained from reports produced by the Department of Water Affairs and Forestry (DWAF, 2003a – k). Water availability was calculated as the firm yield available from the different water supply schemes in each river basin. Land cover data were obtained from the 2000 dataset for South African land cover classes (CSIR, 2000); the data for complementary land cover classes were aggregated to provide data for eight composite land classes that have the most intensive water use. For example, land classified as used for grazing and conservation was combined into a single land-use class based on their similar patterns of water use.

The water crowding index (WCI, the number of people supported by an assured supply of one million cubic metres of water per year; Falkenmark, 1989; Ashton, 2002) was used to estimate the degree of severity of any shortfall in the quantity of water available to the population in each shared river basin for both current (2000) and future (2025) scenarios. Current and planned responses to the existing and projected future water shortages were derived from analyses of national policies (DWAF, 1997; SADC, 1998; Roux *et al*., 2006) and treaties that South Africa has signed with neighbouring states regarding shared river basins (Ashton *et al*., 2006; Turton *et al*., 2006).

In order to evaluate the extent to which the SESs that comprise South Africa's shared river basins are resilient to the pressures exerted by growing populations and political and economic initiatives, we considered the possible responses to impending change in water availability and management responses – i.e. capacity to self-organize - as indicators of social resilience. These features provide insights into the degree that the water resources within South Africa's shared river basins will be able to contribute to sustainable development in the country.

RESEARCH FINDINGS

Spatial and demographic aspects

Approximately 70.5 % (830 295 km^2) of South Africa's total area of 1 219 912 km^2 falls within the four shared river basins, with South African territory forming a large proportion of the total area of each basin (Incomati = 62 %; Limpopo = 44 %; Maputo = 59 %; Orange-Senqu = 61 %).

Current land-use patterns (**Table 1**) reveal the importance of irrigated and rain-fed agriculture, as well as the area occupied by urban and rural communities and degraded land within each basin. The "unspecified" land-use category includes natural vegetation, bare rock, wetlands, waterbodies, protected areas, and areas grazed by livestock and wildlife. Extensive mining, industry and power-generation occur in the Limpopo and Orange-Senqu basins (**Table 1**); these two basins contain over 75% of all such activities in South Africa (STATS-SA, 2007). Commercial irrigated and rain-fed agriculture are important in the Limpopo and Orange-Senqu basins, while forestry is foremost in the Incomati and Maputo basins (**Table 1**). Many rural communities in the Limpopo and Orange-Senqu basins rely on subsistence agricultural activities for their livelihoods (**Table 1**); since 1994, these two basins have been characterized by relatively rapid rates of urbanization (STATS-SA, 2007).

In 2000, the South African segments of the four river basins contained approximately 24.5 million people (55.3 % of the South African population); depending on the population growth rate, this number is expected to increase by between 32 and 73 % by 2025 (**Table 2**). Approximately 59 % of the South African population in these basins is urbanized, while 41 % live in scattered rural communities, many in areas that were previously part of the Apartheid homeland system (Turton *et al*., 2006). These rural areas were - and in many cases still are - poorly serviced, particularly in the less developed sectors of the basins, and thus strongly dependent on local sources of water.

Table 1. Current (2000) land-use within the South African components of the four shared river basins. Land-use categories adapted from CSIR (2000).

River Basin	Area of Landuse Category (km^2)								Basin Total
	Urban	Subsist.	Irrigation	Min/Indus.	Forestry	Dryland	Degraded	Unspecified	
Orange-Senqu	3 999	3 229	5 170	1 497	280	51 796	13 100	521 985	601 056
Limpopo	6 268	9 054	3 541	933	1 761	11 398	16 082	134 188	183 225
Incomati	810	602	945	31	3 545	663	880	21 203	28 679
Maputo	274	412	273	11	3 632	533	699	11 501	17 335

Table 2. Current (2000) population and projected (2025) future population for the South African segments of the four shared river basins, compared with the current (2000) and projected (2025) national population figures for South Africa. (Data adapted from STATS-SA (2007) and DWAF (2003 a – k)).

River Basin	2000 Population ('000s)			2025 Population ('000s)	
	Total	Urban	Rural	Low growth rate (1.1 % / year)	High growth rate (2.2 % / year)
Orange-Senqu	11 319.0	8 101.5	3 217.5	14 879.4	19 502.0
Limpopo	10 905.9	5 351.1	5 554.8	14 336.5	18 790.4
Incomati	1 122.4	676.7	445.7	1 475.4	1 933.8
Maputo	1 165.7	274.4	891.3	1 532.4	2 008.5
Sum of all shared basin segments in South Africa:	24 513.0	14 403.7	10 109.3	32 223.7	42 234.7
South Africa Country Total:	44 326.8	25 709.5	18 617.3	58 270.0	76 372.8

Water supply infrastructure

The prevailing patterns of variable and unevenly distributed rainfall in the shared river basins, combined with high evaporation rates, result in a very low conversion of rainfall to runoff (**Table 3**). In combination with the seasonality of rainfall, river flows are highly variable (Smakhtin, 2001) and it is difficult to ensure that reliable supplies of water are available to meet the needs of all sectors of society.

In response, land-owners and South African water resource managers have constructed numerous water storage reservoirs (dams) that range in size from small farm dams with a capacity of less than 25 000 m^3 to major impoundments with volumes in excess of 4 000 million m^3 (Basson *et al*., 1997). South Africa now has 497 large impoundments, each with a capacity greater than 1 million m^3 (WCD, 2000). The combined storage capacity of these large dams is equivalent to 73.7% of the total runoff generated each year – an unusually high proportion that is unequalled elsewhere in Africa (Basson *et al*., 1997). In the Orange-Senqu and Maputo basins, the combined volume of all large dams exceeds the mean annual runoff (**Table 3**), implying that it would, on average, take longer than a year to completely fill these reservoirs if they were empty. In the remainder of South Africa, the lower dam volume to runoff ratio (**Table 3**) indicates that higher and more reliable rainfalls are received with the result that less storage volume is needed.

Table 3. Comparison of the mean annual precipitation (MAP), mean annual runoff (MAR), runoff to rainfall ratio, average volume of rainfall received, average volume of runoff generated, number of large dams, combined dam volume, and the dam volume to runoff volume ratio for South Africa's shared river basins, and the whole of South Africa plus Lesotho.

River Basin	Basin Area (km2)	MAP (mm)	MAR (mm)	MAR:MAP Ratio (%)	Rainfall Volume (10^6 m^3)	Runoff Volume (10^6 m^3)	No. of Large Dams #	Combined Dam Volume (10^6 m^3)	Dam:Runoff Ratio (%)
Orange-Senqu									
- South Africa	601 056	316.9	10.8	3.4	190 454	6 510	135	17 658	271.3
- Lesotho	30 320	627.9	135.2	21.5	19 038	4 099	3	2 892	70.5
Orange-Senqu Total	631 376	331.8	16.8	5.1	209 492	10 609	138	20 550	193.7
Limpopo	183 225	566.7	28.9	5.1	103 833	5 295	100	3 060	57.8
Incomati	28 679	762.6	99.4	13.0	21 871	2 851	27	440	15.4
Maputo	17 335	770.2	108.9	14.1	13 351	1 888	8	3 068	162.5
Rest of South Africa:	389 617	626.1	75.8	12.1	243 944	29 535	227	9 876	33.4
South Africa + Lesotho:	1 250 232	473.9	40.1	8.5	592 491	50 177	500	36 995	73.7

#: All dams that have a full supply volume greater than 1 million cubic metres.

In some ways, the fact that the volume of large dams exceeds MAR provides a sense of security to communities and to water resource managers that reliable sources of water are available. However, this can lead to optimistic developments with a higher potential for failure during adverse conditions (e.g. droughts and climate change), with serious consequences for social resilience and government's ability to respond to calls for relief.

Water transfers between these countries emphasize the fact that social and economic developments are now linked by mutual dependence on water supplies from the shared river basins and further afield (Ashton and Turton, 2008, in press). While this situation reflects a level of co-operative governance and co-operative management of shared water resources, the relatively large South African population and its rapid growth in demand for water have resulted in South Africa using the largest proportion of these shared water resources (Turton *et al.*, 2006). Importantly, the existing water transfers to neighbouring states are too small to remove the possibility of accusations being levelled against South Africa that water use is inequitable. In addition, the anticipated rates of population growth and economic development in South Africa, coupled with urbanization and international migration, suggest that the existing infrastructure will not be able to fully meet future needs for water. Extensive new (additional) water storage and supply infrastructure are urgently needed (Basson *et al*., 1997; DWAF, 1997).

In addition to large water storage reservoirs, South African water resource managers have built an intricate network of water transfer schemes to transfer water from those water management areas where water is perceived to be more abundant to those where water supplies need to be augmented (**Figure 2**). South Africa receives water from the Lesotho Highlands Water Project in Lesotho while four neighbouring countries (Botswana, Mozambique, Namibia and Swaziland) receive water via South African water transfer schemes (Heyns, 2002).

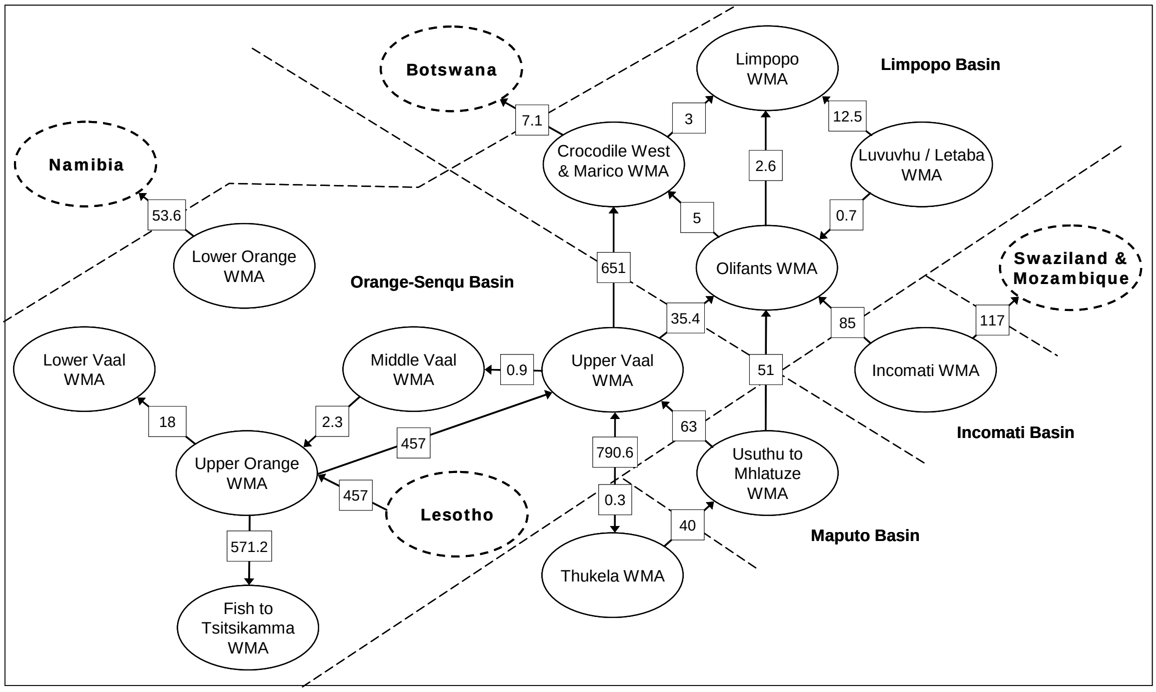

Figure 2. Man-made water transfers between South African Water Management Areas in the four shared river basins and neighbouring countries. Natural (run-of-river) transfers are omitted for clarity. All volumes are in millions of cubic metres per year; dashed lines indicate boundaries between river basins.

Availability of water resources for social and economic development

Comparison of the water available with current water demands in each shared river basin reveals the degree to which the available water supplies can meet demands for water (**Table 4**). In 2000, water demands in the Limpopo and Incomati basins exceeded the available supplies, while supplies in the Maputo and Orange-Senqu basins were sufficient to meet demands. Projected increased demands for water by 2025 have prompted the planning and construction of new water supply infrastructure, which will provide short-term relief for anticipated water shortages in some sectors of the population in the Limpopo basin. However, the projected (2025) demands for additional water to meet the needs of urban and rural communities, industry, mining, power generation and irrigated agriculture – and environmental flows (Republic of South Africa, 1998) - indicate large shortfalls in the Orange-Senqu and Incomati basins (**Table 4**). The shortfalls in water supply are likely to be particularly severe amongst rural communities because of their reliance on river flows, and will also have adverse effects on the agricultural sector of the economy. The anticipated shortfalls could constrain the planned expansion of industrial and mining activities (DWAF, 1997).

Table 4. Comparison of the current (2000) and projected (2025) water needs with the current (2000) and projected (2025) quantities of water available for the four river basins shared by South Africa. (All volumes given in millions of cubic metres per year; data adapted from DWAF (2003a – k).

River Basin	2000			2025		
	Water Available	**Water Needs**	**Shortfall (-) / Surplus (+)**	**Water Available**	**Water Needs**	**Shortfall (-) / Surplus (+)**
Orange-Senqu	9 568	9 208	360	10 816	11 579	- 763
Limpopo	2 585	2 771	- 186	3 778	3 703	75
Incomati	723	972	- 249	837	1 017	- 180
Maputo	847	468	379	849	480	369
Total:	13 723	13 419	304	16 280	16 779	- 499

The data for population and available water in each shared river basin (**Table 5**) reveal that the Water Crowding Index (WCI, the number of people supported by an assured supply of one million cubic metres of water per year) is at adverse levels in every basin. The WCI is an index of the degree to which water supplies are compromised by over-crowding due to population numbers. Theoretically, a WCI value of 1 000 (i.e. 1 000 people per million cubic metres of water; Falkenmark, 1989) represents the reasonable upper limit of the number of people that water supplies can support. When a WCI value exceeds 1 000 it is increasingly difficult to provide sufficient water to meet all of society's needs for water for social and economic development. However, while the WCI provides a general measure of the water stress on society in the face of changing conditions, the 'reasonable limits' are subjective and will reflect features of the prevailing socio-economic conditions. For example, the particular socio-economy of a developing country may suggest that a water resource can accommodate more people before 'crowding' occurs because they have not grown used to higher levels of water use. However, the fact that a greater proportion of the population is already at or below the 'reasonable limit' provides less latitude and opportunity for that population to adapt and thus lessens their potential to self organize in the face of stress.

Table 5. Current (2000) and projected (2025) populations and water resources available (including water transfers) in the South African segments of the shared river basins, with values for the Water Crowding Index for each basin. (Data adapted from DWAF (2003 a – k) and STATS-SA (2007)).

River Basin	2000			2025		
	Population ('000s)	**Available Water (10^6 m^3 / yr)**	**WCI**	**Population [High] ('000s)**	**Available Water (10^6 m^3 / yr)**	**WCI**
Orange-Senqu	11 319.0	9 568	1 183	19 502.0	10 816	1 803
Limpopo	10 905.9	2 585	4 219	18 790.4	3 778	4 974
Incomati	1 122.4	723	1 552	1 933.8	837	2 310
Maputo	1 165.7	847	1 376	2 008.5	849	2 366

The 2000 WCI value exceeds 1,000 in each of the four shared river basins indicating that chronic water shortages occur (**Table 5**). These water shortages already extend beyond the driest months of the year and become worse during prolonged periods of low rainfall and river flows. Social groupings – such as the under-serviced rural communities – can be envisaged as going through a downward trend of resilience, where each 'recovery' (adaptive renewal) is weaker, until a threshold is reached where government has to engage crisis management. The high WCI value of 4 219 for the Limpopo basin in 2000 indicates that this basin is already well "beyond the water barrier" (given as a WCI value of 2 000; Falkenmark, 1989) and that inadequate water supplies already constrain social and economic development.

Water shortages in the Limpopo basin have prompted plans to build several new dams and their associated water storage and supply infrastructure in the component water management areas (DWAF, 2003a - d). Similar plans are being drawn up for the other shared river basins. However, plans to alleviate the water supply situation in each river basin through the provision of new water supply infrastructure by 2025 will likely be insufficient if the population grows at even its lowest projected growth rate (**Table 2**). Despite a planned increase of approximately 18% in the quantity of water available, the WCI values for each river basin worsen by 2025 (**Table 5**), with the Limpopo, Incomati and Maputo basins remaining "beyond the water barrier". This will make it difficult for South Africa to achieve its social and economic growth aspirations. As the water barrier is approached, so increasingly is society required to adapt. Two strategies for adaptation are already apparent: demand management and migration to areas of more consistent supply. Both of these have profound implications, at the local and national scales, for social resilience and planning for reliable supplies of water.

Segmentation of the current and projected water needs into the different economic sectors (**Table 6**) reveals that water shortages will not be experienced equally by all sectors of the economy and some reallocation of water between sectors has already been planned.

Table 6. Current (2000) and projected (2025) South African sectoral water needs in each shared river basin, and the projected percentage increase in each water use sector between 2000 and 2025. (Water needs data adapted from DWAF (2003a –k)).

River Basin	Sectoral Water Needs (10^6 m^3 / year)						
	Urban	Rural	Irrigation	Mining & Industry	Power Generation	Forestry	Total
2000							
Orange-Senqu	2 238.9	468.8	6 018.3	660.2	181.8	0	9 568.0
Limpopo	625.6	118.9	1 377.8	214.6	204.2	43.9	2 585.0
Incomati	57.8	19.5	518.4	22.4	0	104.8	723.0
Maputo	23.7	28.8	591.2	2.5	0	201.6	847.8
2025							
Orange-Senqu	3 958.7	421.8	5 591.9	594.9	248.8	0	10 816.0
Limpopo	1 541.4	151.1	1 499.9	279.6	256.9	45.3	3 774.2
Incomati	141.5	20.1	541.5	23.4	0	109.6	836.2
Maputo	53.5	28.0	571.4	2.5	0	194.4	849.8
Percentage Increase:							
Orange-Senqu	76.8	- 10.0	- 7.1	- 9.9	36.8	0	13.0
Limpopo	146.4	27.1	8.9	30.3	25.8	3.2	46.0
Incomati	144.6	2.9	4.5	4.6	0	4.6	15.7
Maputo	125.5	- 2.7	- 3.4	0.2	0	- 3.6	0.2

The greatest projected increase in water demand in 2025 (between +76 and +146 %) will be in the urban sector in each basin, with smaller increases in the power generation sector in the Orange-Senqu (+37 %) and Limpopo (+26 %) basins, and the mining plus industry sector in the Limpopo basin (+30 %). In addition, there is a projected 27 % increase in the water needed by rural communities within the Limpopo basin, which also has the greatest overall increase in water demand (+46%). The Maputo basin has the smallest projected increase in water demand

(+0.2 %), while the Orange-Senqu and Incomati basins have approximately equal but intermediate (13-15 %) increases (**Table 6**). The projected decreased demand for water for irrigation and forestry, plus reduced water demands in the rural sector, suggest that water previously used by these sectors will be re-allocated to the rapidly-growing urban sector. The projected decreased demand for water within the under-serviced rural sector is attributed to a decline in the rural population (due to increased urbanization) and not to a drop in the per capita demand for water.

Social and political responses to the problems of water management

The chronological sequence of social and political events that characterized South African approaches to the management of shared water resources is shown in **Figure 3** (also, see Chapter by Funke *et al*.). Prior to the arrival of Dutch and then British colonial settlers and administrators, the indigenous peoples of South Africa exercised their prior use rights on all water systems, though no records are available as to any form of control that might have been placed on the use of water. This contrasts with control that was commonly exercised over rights of access to and use of water associated resources in many parts of Africa (Heeg and Breen, 1994; Abacar, 2000; Hara *et al., 2002)*. From the early days of Dutch and later British occupation, water resource management was controlled centrally and rivers such as the Orange-Senqu provided convenient boundaries between countries. The need for water storage reservoirs and irrigation schemes dominated water resource management until the early 1900s. The period spanning the late 1880s to 1910 was marked by increased government-sponsored water supply and irrigation infrastructure, the drilling of numerous boreholes in arid parts of the country, and the establishment of the first Water Board (Rand Water) in the Orange-Senqu basin. In addition, several laws were introduced to regulate the management and use of water, especially irrigation (**Figure 3**). While these activities strengthened the social resilience of urban and some rural communities, they continued to exert increasing pressure on the aquatic ecosystems and reduce their resilience.

The period between 1910 and 1950 (**Figure 3A**) witnessed the passing of the first Water Act and additional laws to control irrigation and water conservation, as well as the first international agreement between South Africa and Portugal on rivers of mutual interest. In the context of this chapter, this treaty applied to rivers shared with Mozambique. This treaty is particularly relevant for rivers shared with Mozambique – rather than Angola - in the context of this chapter. This period was also marked by the construction of numerous farm dams, water storage reservoirs and irrigation schemes in the drier portions of the Orange-Senqu and Limpopo basins (**Figure 3A**). With the onset of Apartheid in 1948, the adverse effects of earlier legislation – in particular the Natives Land Act of 1913 – were enforced and accentuated, minimizing the ability of black people to own land and restricting their right of access to water (Turton, 2003). The Apartheid system of government strengthened the social resilience of white urban and rural communities but dramatically reduced the social resilience of black communities, most of which occupied rural settings.

The period between 1950 and 1994 was marked by a sharply increased emphasis on restricting black people to designated "homeland" areas based on their ethnic and linguistic origin, further diminishing the social resilience of these communities. At the same time, the Apartheid government strengthened its system of 'centralized command and control' over water supplies, with a dramatic increase in the number of dams and irrigation schemes designed primarily to meet the water needs of white farmers and the mining industry, strengthening the social resilience of these predominantly white rural and urban communities. The Commission of Enquiry into Water Matters (initiated in 1966) noted in their 1970 report that future economic development in South Africa could become compromised due to inadequate supplies of water. This prompted the compilation of a Total Water Strategy for the Vaal Triangle in 1980 to ensure that sufficient water would be available for South Africa's economic and industrial heartland. This helped to reinforce the social resilience of the predominantly white urban communities in this area.

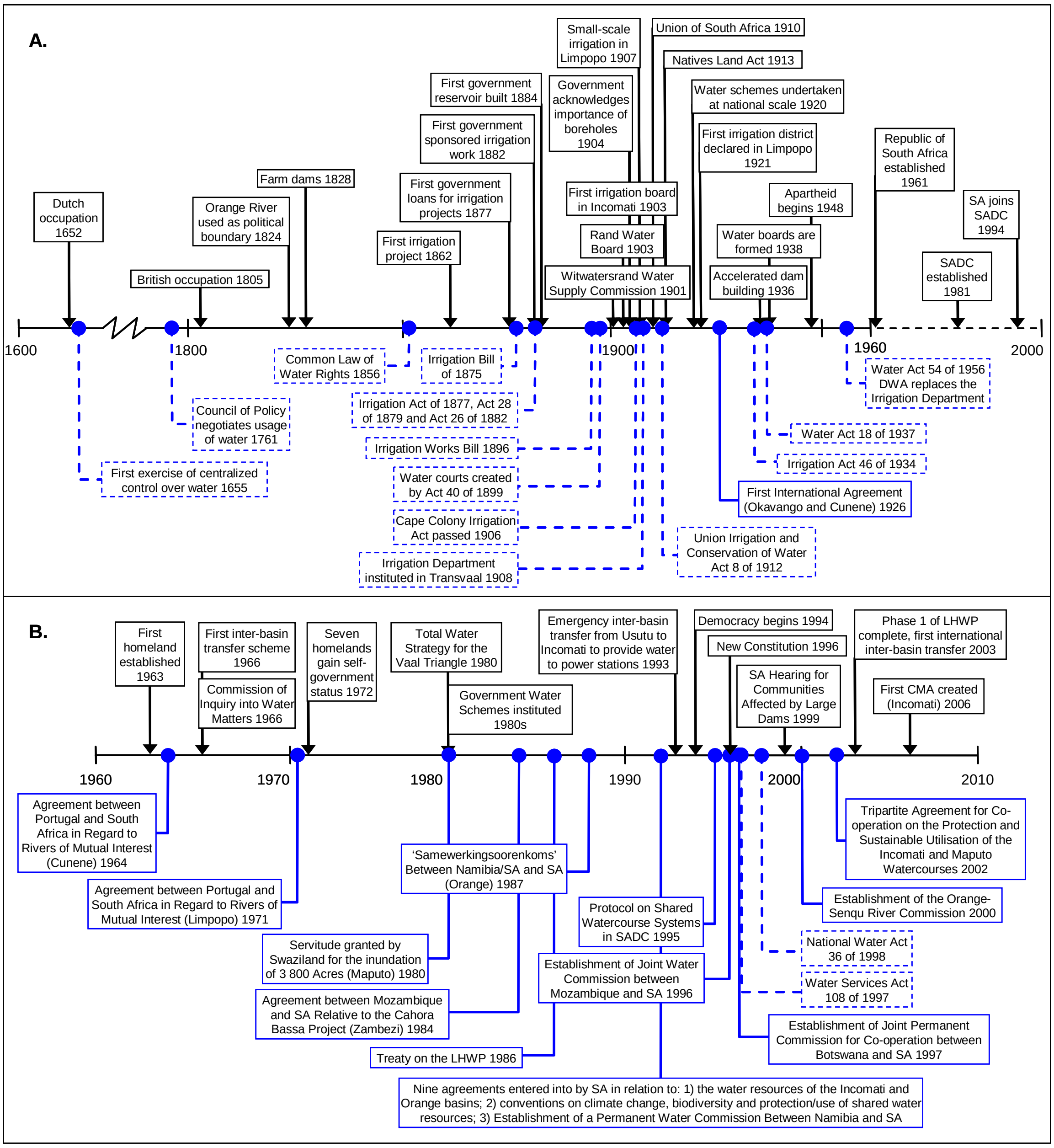

Figure 3. Chronological sequence of major water-related political events (black boxes), international agreements (solid blue boxes) and national legislation (dashed blue boxes) that influenced the management and use of water resources in South Africa's four shared river basins. **A.** Sequence from the early 1600s; **B.** Expanded sequence for the period 1960 – 2010. Data adapted from Turton (2003) and Ashton *et al*. (2006).

Between 1964 and 1971, South Africa and Portugal signed additional international agreements over rivers of mutual interest – in particular the Cunene and Limpopo rivers. These were followed by the servitude agreement with Swaziland for the inundation of a portion of Swaziland territory by the Jozini Dam on the Maputo River and a working agreement with officials from South West Africa, now Namibia, over the lower Orange-Senqu River (**Figure 3B**).

The onset of a democratic government in 1994 marked the start of an abrupt reversal in the governance processes that had helped to diminish the social resilience of black communities, and also signalled the wider acceptance of South Africa amongst the international community. Since then, (**Figure 3B**) South Africa has signed several agreements with neighbouring states in the Southern African development Community (SADC) region and internationally (Ashton *et al*., 2006). In particular, South Africa entered into co-operative agreements with neighbouring states to manage shared water resources - in the Incomati, Limpopo, Orange-Senqu and Maputo basins (Turton, 2003; Ashton *et al*., 2006) - according to the principles of the revised SADC Water Protocol (SADC, 2001). When all of their provisions have been implemented, these agreements will strengthen national processes of water governance and enhance the social resilience of all communities in South Africa. The intention of these provisions is to enhance - through more secure access - the ability of nations to self organize at international scales. However, given the very high level of runoff exploitation in South Africa (**Table 3**), achieving this resilience will depend on trade-offs that may have undesirable consequences for the capabilities of South Africa to remain resilient as internal demands for water rise. This understanding suggests a need for commitment to improved efficiency in the use of water.

The new South African government reviewed and revised all water laws in South Africa, ratifying the Water Services Act in 1997 and the landmark National Water Act in 1998 (Republic of South Africa, 1998). The National Water Act defined the common property aspects of water; separated ownership of land from ownership of water; confirmed the need to ensure that aquatic ecosystems receive sufficient water to function properly; stipulated the need to ensure that neighbouring states could utilize international (shared) water resources equitably; entrenched the right of all South Africans to have adequate access to wholesome supplies of water; and conferred custodianship of the country's water resources on the Department of Water Affairs and Forestry (DWAF, 1997). These provisions helped to remove earlier legal impediments that had progressively diminished the social resilience of urban and rural black communities.

The National Water Act recognizes the unity of the hydrological cycle and the need to manage water as a single resource, thereby promoting the philosophy of Integrated Water Resource Management (IWRM) and encouraging all stakeholders to make use of opportunities to engage in decision-making processes (Ashton, 2007). Ideally, this process should strengthen the social resilience of communities by enabling them to participate in processes that affect their lives and livelihoods. However, because the rural sector is the least influential, merely having the opportunity – just described - does not necessarily imply that they have the power to influence water allocation. Ultimately, responsibility for managing the water resources within each of South Africa's 19 Water Management Areas will be devolved to Catchment Management Agencies (Republic of South Africa, 1998), though ultimate responsibility for international (shared) river basins remains with central government. The National Water Act is regarded as arguably the most innovative and far-reaching water law in the world and set the scene for dramatic improvements in the way that water resources were to be managed (Postel and Richter, 2003).

The World Commission on Dams (WCD) conducted several public hearings in South Africa during 1999 on the social and economic impacts caused by the construction and operation of water supply reservoirs. Their report (WCD, 2000) provided several suggestions to improve decision-making processes, strengthen the social resilience of communities affected by dams, and broaden the benefits of prudent water resource management. Whilst impounding water remains a dominant paradigm for promoting urban social resilience, there is little additional water available for storage and some stakeholders have continued to express concerns that the construction of any new reservoirs could lead to further deterioration in aquatic ecosystems from their natural state with a corresponding decline in resilience (e.g. O'Keeffe, 1989; Davies and Wishart, 2000; Nel *et al*., 2007). As the presently very high level of runoff exploitation is exacerbated, it will become increasingly difficult to meet environmental water requirements with direct consequences for both ecosystem and rural social resilience. The very high level of runoff exploitation in South Africa means that it will be increasingly difficult – and expensive - to "trap" additional quantities of water without transforming the river systems.

The early part of the 2000s marked the completion of the first phase of the Lesotho Highlands Water Project; water is transferred northwards from the Katse and Mohale dams in Lesotho to the Vaal River system, for use in the Gauteng Province, South Africa (**Figure 3B**). While this has strengthened the social resilience of urban communities in South Africa, it also emphasizes the wide socio-economic discrepancies between urban and rural populations and their access to and patterns of water use. Despite these investments in water supply infrastructure, many rural people are not serviced and their resilience in the face of water insecurity has weakened. In addition, the first of nineteen proposed Catchment Management Agencies - (the Incomati CMA for the Incomati WMA) - was created in 2006.

DISCUSSION

The water storage and supply infrastructure that has been developed in the South African segments of the shared river basins is insufficient to meet all of the existing demands for water and new infrastructure is urgently needed. Projections of future population growth and increased demands for water will worsen the water supply situation and increase pressure on government to provide adequate supplies of water. While current plans to expand water storage and supply infrastructure (DWAF, 1997; DWAF, 2003 a-k) will provide some short- to medium-term relief for those in the formal water economy, increased levels of water resource exploitation will place further stress on the country's water resources (Ashton and Turton, 2008, in press). The only water resources available are those of river systems elsewhere in South Africa, which have not yet been exploited to the same extent as those of the Incomati, Limpopo, Maputo and Orange-Senqu. This will increasingly disadvantage those rural communities that rely directly on perennial sources for their water supplies. Since the increasing risk of water shortages is inevitable, there is a clear need to plan for water shortages and the associated consequences for social resilience – especially in rural communities who are most vulnerable. Existing remedial strategies are unlikely to be appropriate in situations where crises are experienced more frequently. For example, the transformation of previously perennial rivers into seasonal or episodic rivers will result in communities experiencing more frequent periods of water shortage.

South Africa's neighbours share similar pressures to develop additional water supply infrastructure, despite having smaller populations than South Africa (CIA, 2007). The water supply situation in the shared basins is aggravated by periodic, prolonged droughts that are often 'broken' by severe floods. This causes high levels of stress – particularly to poverty-stricken residents of rural areas – and emphasizes the vulnerability of communities that rely on run-of-river water resources (Basson *et al*., 1997; Ashton, 2002; Turton *et al*., 2006). While this situation is not unique to southern Africa (Falkenmark, 1989), the scale and severity of the social and economic threats posed by inadequate water supplies in the region requires improved planning processes and the design of preventative and remedial strategies if large-scale hardship and possible future disputes are to be avoided (Ashton, 2002). Examples of such strategies could be the emergency relief programmes where water supplies are provided to communities by mobile tankers.

The flows in each perennial river system – and several of the seasonal river systems – have been regulated by successive sets of water storage reservoirs and inter-basin transfer schemes. While South Africa produces the largest fraction of the total runoff in each basin, almost all of this water is used in South Africa. This has led to a growing concern that the "shares" of water available to each basin state may not be equitable (Pallett, 1997; Mohamed, 2003; Turton *et al*., 2006). South African proposals to use additional quantities of water have heightened these concerns amongst her neighbours (Pallett, 1997; SADC, 1998; Heyns, 2002).

Certain plans to increase the extent to which these river systems are exploited have elicited adverse public reaction. For example, Couzens and Dent (2006) discuss the range of opinions on the controversial De Hoop Dam project on the Steelpoort River, a tributary of the Limpopo basin. Therefore, despite the need for new water supply infrastructure, there is concern that the construction of new water storage reservoirs and water transfer schemes will exert additional adverse effects on these river systems – such as perennial rivers experiencing increasingly frequent cessation of flow - with the added potential to further disadvantage affected rural communities and the country's neighbours (Mohamed, 2003). While current plans to deal with water shortages are still based on conventional approaches to augment water supply and manage (reduce) demands for water, it appears that too little attention is paid to managing community resilience in the face of increasing frequency and severity of risks.

The widespread public concern about water resources in the four shared river basins emphasizes the critical need for South Africa to adopt prudent water resource management options (Couzens and Dent, 2006). From the start of centrally-organized water resource management by the Dutch East India Company, through successive British and then South African governments, increasing proportions of the surface and groundwater resources in the four basins were used to meet specific political and economic objectives. Prior to 1994, these objectives centred on the provision of water for agriculture and industry – favouring the white minority of the population - and helped to strengthen and entrench government control. After 1994, the separation of land and water ownership (Republic of South Africa, 1998) represented a dramatic change of course and reflected the new democratic government's desire to redress past political inequities and alleviate the prevailing poverty experienced by millions of black people. Inevitably, these corrective actions – essential and desirable though they are – have placed additional stress on the country's shared water resources.

The dynamic interactions that link the different components of the complex social-ecological system that comprises each of the four shared river basins, and how these affect social resilience, are shown in **Figure 4**. These features display subtle yet important differences in the ways that they influence the social resilience of urban and rural communities. Initially, development imperatives within South Africa and each neighbouring country drive social and economic growth in urban and rural settings, as well as processes of regional co-operation over the management of water resources. In each country, population growth increases the demand for water and prompts improved water allocation by the respective governments. Since rainfall is erratic and water supplies are variable or unreliable, water storage reservoirs ensure that reliable supplies of water are available for urban areas and industry.

For rural communities that lack access to formal water supply infrastructure and rely directly on rivers, springs and wells for their water supplies, water storage is achieved for some by the construction of small farm dams and reservoirs, while others remain dependent on perennial sources. Climatic effects such as droughts and floods – as well as the potential adverse impacts of climate change on the availability of runoff (de Wit and Stankiewicz, 2006) – reduce the quantity of water that is available for capture and storage in impoundments and diminish the quantity of water available for direct use by poor rural communities. Where the storage capacity of larger reservoirs is insufficient to satisfy the demands of urban and industrial users, water supplies can be augmented by water transfers from areas where water is available (Basson *et al*., 1997). Rural communities lack the financial and technological resources to construct water transfer schemes, and are therefore unable to access their potential benefits, making them more vulnerable to local variations in the supply of water. As South Africa seeks to rectify its balance of trade deficit by generating a "new wave" of industrial development, one can posit that - as the focus will likely be urban - rural communities will feel additional stress and may be encouraged to migrate to urban centres.

The availability of sufficient water has a direct effect on the cost of water, and increasing costs have a negative effect on the resilience of urban communities (**Figure 4**). Adequate water storage has a positive effect on the resilience of urban communities and their governance systems and this, in turn, enhances government-based governance systems. Water transfers and increased water storage have negative consequences for patterns of river flow, and decrease the resilience of river ecosystems (**Figure 4**). The resilience of river ecosystems impacts directly on the resilience of river-associated rural communities (Walker and Salt, 2006), while the resilience of urban communities and rural communities, in combination, exerts a direct influence on community-based governance systems. The presence of a vibrant and effective community-based governance system improves the resilience of the water-based social-ecological system (Van der Leeuw and Aschan-Leygonie, 2000; Walker *et al*., 2004) and this, in turn, has direct effects on regional poverty levels and population growth (**Figure 4**). Ultimately, while all of the factors are closely interlinked and exert a variety of effects that are moderated or accentuated by feedbacks, these feedbacks may or may not affect the resilience of the system.

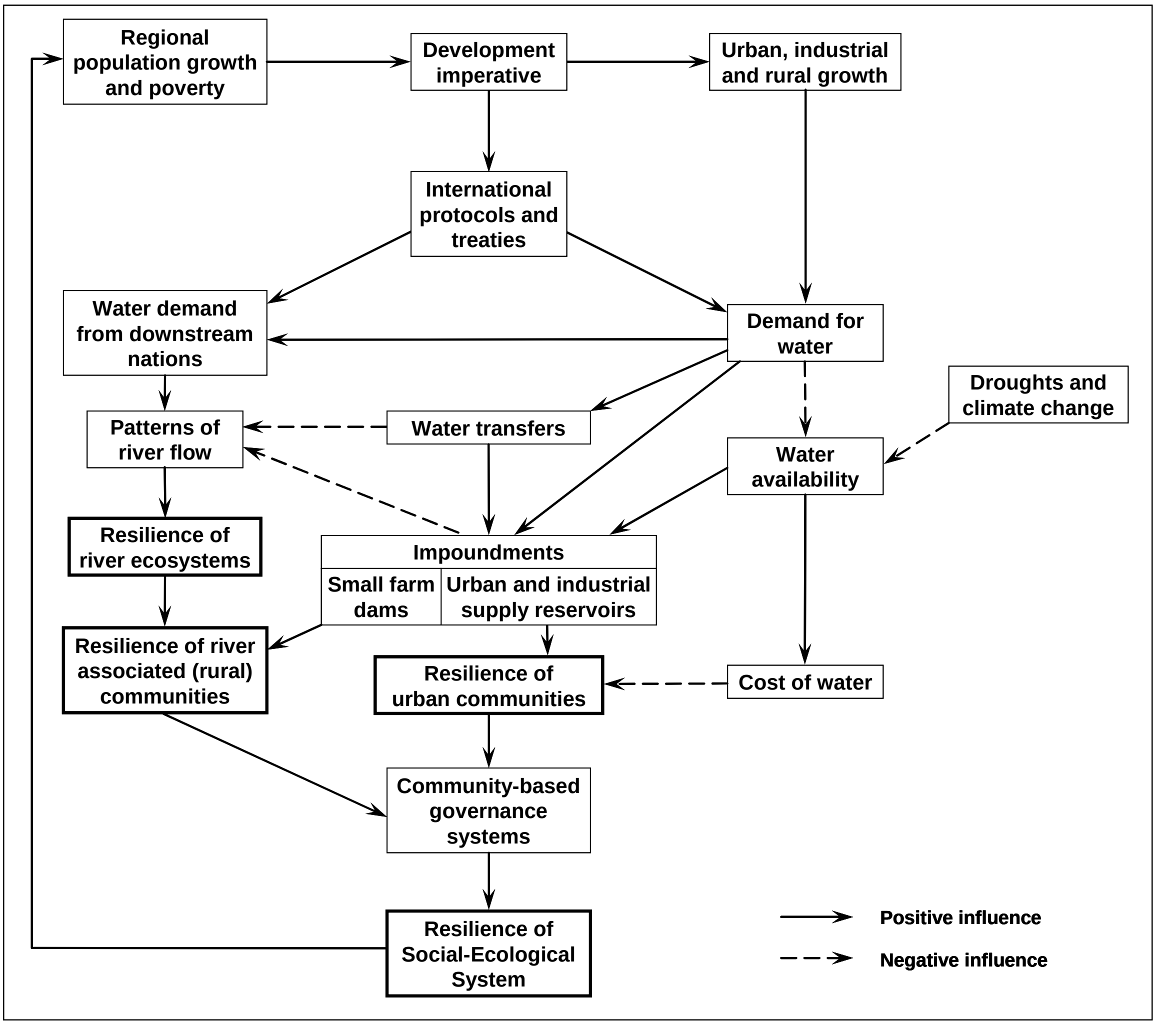

Figure 4. Factors and processes that influence the social resilience of urban and rural communities, and the ecological resilience of river systems in the four shared river basins. The negative influences are those that have the most compelling need for effective management responses.

It is clear from **Figure 4** that a decline in social resilience will potentially have negative effects on the prevailing governance system, which will reduce the capacity for government to implement national policies that promote sustainable development as well as the efficacy of international agreements and protocols. This will have an adverse effect on the way people and governments respond to demands for water and the ways that water is allocated and used by communities in the countries that share these resources. Essentially, this could then become a positive feedback mechanism leading to the collapse of governance systems, followed by an increase in unmanaged demands for water and, ultimately, to a change in the state of the respective river systems.

Increasing stress exerted on societies by water resources is reflected as a decline in the per capita quantity of water that can be supplied to meet the needs of society. Almost all of the suitable sites for water storage dams have been exploited and the construction of new (additional) dams has become increasingly expensive (Bohensky and Lynam, 2005). In addition, Davies and Wishart (2000) have indicated that flow regulation and inter-basin water transfers have modified natural river flows “beyond recognition” and the flows of many perennial river systems are now seasonal or episodic. As highlighted earlier, the shared river basins have little potential remaining – in the form of additional water resources – that can be exploited to reduce the current high WCI values. As familiar ecological goods and services decline or are lost, people have had to either go without or seek other affordable sources. In the process, the ability of society to cope with (or adapt to) and self-organise in the face of the dynamic changes in water availability indicate that some sectors of society – particularly the urban sector – have historically become increasingly resilient (**Figure 5**). If However, faced with few options to increase guarantees of water supply, and if the social system is unable to cope with the declining per capita volumes of water that we have described earlier in this chapter, for example through improved efficiency of water use or inter-sectoral re-allocations of water, then there is an increased risk that the social system will change to a different – and probably more confrontational - state or level (**Figure 5**).

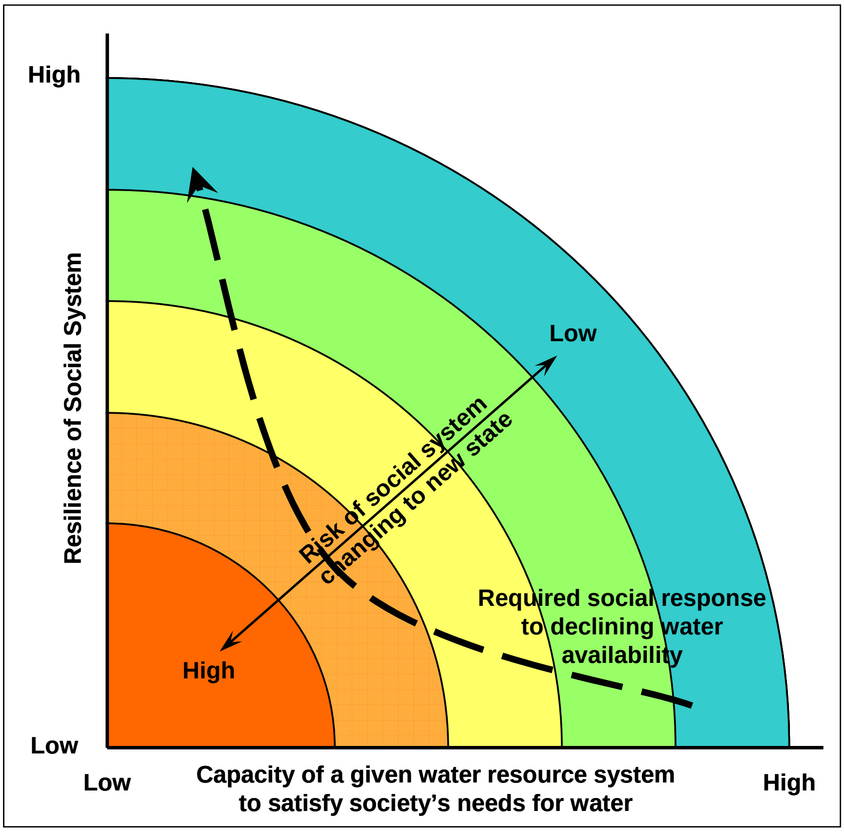

Figure 5. Conceptual diagram illustrating the trajectory of required social responses to a progressive reduction in the capacity of a given water resource to satisfy society’s needs for water. If society fails to achieve the required levels of social resilience there is an increased risk of adverse change to the social system.

Resilience of governance in the face of scarcity requires the reinforcement of social resilience founded on a willingness to commit to balancing equity, efficiency and sustainability (Van der Leeuw and Aschan-Leygonie, 2000). The ‘centralized command and control’ system exercised by successive South African governments controlled people’s access to and use of water resources. This will have to continue –

and receive greater emphasis – in the future. Social and economic drivers have prompted government to be the 'provider' and, in the past, the ample water resources available were managed simply to meet demands. This was a relatively easy responsibility for government to meet, in the same way that it had a responsibility to provide energy and transportation infrastructure. However, where future demands for water exceed the available supplies, society must accept that government will have to make trade-offs as it manages society's demands for water to cater for considerations of equity, efficiency and sustainability. These trade-offs could, for example, entail an increased shift towards improved efficiency of water supply.

Government control and financial assistance in the form of subsidies has helped to strengthen social resilience to external 'shocks' such as droughts and floods. Subsequent development of inter-basin water transfer schemes (**Figure 2**) has extended and entrenched government control, and increased the apparent social resilience, particularly in urban situations. However, climate change will likely reduce the availability of water in the future (de Wit and Stankiewicz, 2006) - accentuating the effects of population growth – and emphasizing the need for innovation to maintain urban social resilience and build resilience in rural communities in the face of growing scarcity and inter-sectoral reallocation of water. This will require resilient governance systems in which society acknowledges that it has to continually adapt if it is to accommodate the principles of equity, efficiency and sustainability (Walker and Salt, 2006). In essence, the process should reinforce social capital (trust and cohesion) so that people make adjustments for the common good. Fortunately, the 'rules' of water allocation are flexible - able to change with altered water availability - while the civic processes for securing support for the rules can also be adapted to suit new circumstances.

Additional evidence for increased (social) resilience of South Africa's system of water resource management is provided by the increased number of international agreements and treaties that South Africa has entered into with her neighbours for the management of shared river basins (Ashton *et al*., 2006; Turton *et al*., 2006). These formal agreements, rules and norms are a fundamental attribute of resilience (Walker *et al*., 2004) and represent a new scale of governance that improves the alignment of social resilience with the scale of a water resource (the river basin). This also demonstrates that, over time, there has been an increase in the spatial scale of social resilience from individual pioneers through small groups and enterprises to governments and the international community. However, while these agreements and treaties demonstrate that the basin states concerned share a desire to co-operate over water resource management, the technical committees and commissions that have been set up are not sufficient on their own to ensure that water resources are shared equitably by the countries sharing the four river basins (Ashton *et al*., 2006). Clearly, while South Africa's desire to co-operate with her neighbours may not be founded in law or even social norms and thus may not provide a firm foundation for resilience, South African law stresses processes that support social capital and thus resilience. Co-operation remains an explicit response that reflects the prevailing patterns of social resilience and good governance.

The escalating use of water by the growing population and expanding economy has been accompanied by a decline in the per capita volume of water available for use and a simultaneous deterioration in water quality. This was accompanied by a progressive decline in the health of most aquatic ecosystems, particularly those of the shared river basins (Davies and Wishart, 2000). However, while the declining health of these systems reflects the degree to which they have been altered by society's needs for and use of water, it also reflects how society as a whole has chosen to balance efficiency, equity and sustainability (Van der Leeuw and Aschan-Leygonie, 2000). At smaller scales, societal choices may leave little opportunity for choice as they drive adjustments, forcing groups and individuals into trade-offs between efficiency, equity and sustainability in order to survive. However, information is linked to the exercise of power and so to control and bias (Giddens, 1979; Coopey, 2004). Because the two primary social groupings (urban and rural) seldom hold a shared understanding and, because power relationships are unequal, the choices and trade-offs are subject to manipulation with significant implications for social resilience (Langridge *et al.*, 2006). In the short-term, some groups may become resilient whilst others become less so but, because the groups are connected, delayed consequences are inevitable.

Notwithstanding the prospects of advancing water scarcity and its implications for societal resilience, there are strong calls to allocate sufficient water to maintain the structure and functioning of aquatic ecosystems in a 'preferred state' as jointly defined by stakeholders and water resource managers (e.g. O'Keeffe, 1989). This emphasis has been codified in the National Water Act as the 'Ecological Reserve' (Republic of South Africa, 1998), but given the widespread scarcity of water in these and other South African river basins, it has become increasingly problematic to justify provision of the requisite volumes of water in the face of a growing sense of societal vulnerability. Yet, this vulnerability is most acutely felt among rural people for whom ecological flows hold most relief. The challenge of balancing the exercise of power in allocation of water for the Environmental Reserve is exacerbated by prolonged regional droughts, high levels of poverty, especially among rural people, and the potential adverse impacts of climate change (de Wit and Stankiewicz, 2006).

CONCLUSIONS

We have illustrated that the effects of water scarcity will be acutely felt within four interconnected subsystems, the international, urban, rural and ecological subsystems. The imperative for economic growth in the region, particularly through industrial production, provides a pull for resources toward nations and urban communities within them. These two sectors already exert most influence in decision making and we can envisage that they will use this to strengthen their ability to self organize thereby enhancing the resilience of these subsystems. In doing so the resilience of the rural and ecological subsystems will become increasingly stressed and as the ecological support system for rural communities declines, urban migration will be favoured. This understanding encourages us to appreciate the central importance of a systems approach to decision making around the allocation of resources in complex SESs. Exposing the feed forward and backward loops and emergent properties enables learning about likely and emergent consequences of allocation decisions for system resilience. It also encourages us to seek fundamental solutions whilst addressing the increasingly urgent symptoms. Importantly, exposing the dynamic connectedness between the subsystems encourages appreciation that integrated resilience can be achieved only when we incorporate robust, informed dialogue in governance directed at trade-offs in access to and use of scarce natural resources such as water.

The available evidence on water resources and their use in the South African segments of the four shared river basins we have described indicates that these resources have either reached, or are fast approaching, the point – so-called “basin closure” (Turton and Ashton, 2007, in press) – where there is insufficient water for any additional uses if current patterns of use continue unchanged. The flows in several tributary rivers in the four shared basins have already been transformed from perennial to seasonal, indicating that the character of these rivers has changed (Davies and Wishart, 2000). Importantly, these changes have profound effects on those rural and urban communities who depend directly on river-related resources. Plans to construct new water storage and transfer infrastructure to meet the current and anticipated demands for water in South Africa will provide relatively short-term relief and represent a unilateral approach (Nkhata *et al*., 2007) that will not necessarily benefit the other states that share these river basins.

Given the current and anticipated demands for water in the four shared basins, combined with the anticipated effects of climate change on river flows (de Wit and Stankiewicz, 2006), it will be extremely difficult to reverse any of the existing changes in an attempt to “improve” their flow patterns if society chooses such an option. The prevailing water shortages also suggest that it will be difficult for South African water resource managers to provide sufficient water to meet the ecological flow requirements of these river systems, as required by the National Water Act (Republic of South Africa, 1998). This situation will progressively worsen as the South African government strives to meet the water supply targets laid out in the Millennium Development Goals (UN Millennium Project, 2005) and to comply with the ideals of the revised SADC Water Protocol in relation to shared river basins (SADC, 2001). If this issue is not addressed it could also worsen international relations between South Africa and the neighbouring states that share these river basins (Ashton, 2002).

The increasing social and economic stresses posed by current and impending water shortages are not equally distributed – either spatially across river basins or socially across urban and rural communities. In addition, the capacity or resilience of communities to respond appropriately to these stresses differs widely according to their social and economic circumstances. Therefore, these differentials need to be recognized and accounted for in the governance processes associated with the management of shared water resources. When trade-offs are made, we need to be aware of the likely long-term consequences that may arise and we should anticipate the appearance of unexpected consequences in the different social domains.

Our understanding of the importance of good governance processes, coupled with improved legislative instruments such as the National Water Act and regional treaties over shared water resources, suggests that there has been an increase in overall social resilience in South Africa. Part of the evidence for this increased social resilience can be seen in the participative processes that have led to the launching of Catchment Management Agencies (CMAs) for each of South Africa’s 19 Water Management Areas. Nevertheless, the Department of Water Affairs and Forestry cannot – and will not - absolve itself of the overall responsibility and accountability for the access to and use of water - a crucial national asset.

South African water resource managers and their counterparts in neighbouring states will need to agree on appropriate collaborative mechanisms (Nkhata *et al*., 2007) that will allow their respective governments to abide by the provisions of regional treaties, sustain the reasonable social and economic development aspirations in each country, and guard national sovereignty. Among the options that relate to water are, for example, strategic approaches to development that reflect appreciation for a shared dependency on water, increased efficiency of use and shared tariff structures that make it more attractive for coastal locations to use desalination. The efficacy of such collaborative arrangements will reflect the social capital that exists among nation states and water users (Nkhata *et al*., 2007). The mere existence of a regional water-sharing treaty is no guarantee that water will be shared – equitably or otherwise. Effective implementation of these treaties requires firm commitment from each state to deploy the financial and professional resources that will encourage and enable each state to abide by its responsibilities (Ashton, 2002). Failure to achieve this ideal will impede sustainable development across southern Africa.

South African society is clearly partitioned into rural communities, which commonly depend directly upon run of river for a host of water-related goods and services, and urban communities that rely on water abstracted from impoundments to generate goods and services. The short-term availability and accessibility of water acts as a driver that will test the social resilience of each of these sectors in South Africa, while also testing the social resilience of international society in the shared river basins, both directly and indirectly. Therefore, the dynamic balance between demand for water and the availability and accessibility of water – either in water storage impoundments or as surface runoff in rivers – will exert significant effects on social resilience. Since water shortages have noticeably different effects on the social resilience of urban and rural groups, one outcome might be that rural water shortages could fuel the migration of communities from rural to urban settings. If we accept that equity, efficiency and sustainability are key features of resilient social systems (Folke *et al*., 2005), the central challenge is then to ensure that governance systems are sufficiently adaptive to allow informed trade-offs to be made between these attributes at the required urban, rural and international scales. Because of the fundamental requirement for water and the anticipated increasing scarcity of water, decisions will have to be guided toward achieving the most good (utility and efficiency) for the greatest number. We suggest that an inevitable consequence will be increased stress on the resilience – particularly of rural and ecological systems. It seems to us that it is opportune to focus discourse on what future states might be, and how best to foster resilience in a changed state, rather than imagining that they can be sustained in their present state or that this can be improved with significantly larger allocations of water.

Importantly, the trade-offs occur at different times and in different contexts. The trade-offs in the planning context are less pressing and personal than those that occur during a time of water shortage. Given the probability that water shortages will become more frequent – leading to more severe failures of supply - well-considered plans and a high level of preparedness for crisis/disaster management are essential if social resilience is to be enhanced. Central to being better prepared is a social-ecological systems approach to risk management. This would require continuous updating and evaluation of the likelihood and consequences of shortages projected in time and space, so that intervention becomes a planned process rather than a spontaneous response.

South African society is not a single, coherent group but comprises people across a wide spread of social and economic circumstances that suggest an economic continuum from urban (predominantly rich) to rural (predominantly poor) communities. The poorer and more vulnerable (rural) elements of society are not well positioned to cope with current or impending changes in water availability and accessibility, and are therefore the most vulnerable and least resilient. This socio-economic characteristic appears to be shared by South Africa's neighbours, as reflected in the high values for their GINI coefficients (CIA, 2007), and indicates that these countries face the same or similar problems to those faced by South Africa. It is important to acknowledge that this interpretation is incomplete, emphasizing the urgent need for more detailed research and analysis on this pressing topic.

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REFERENCES

ABACAR, A.J. (2000). *A Case of Inland Fisheries Management in the Lucheringo-Rovuma-Messinge River Systems, Northern Niassa, Mozambique: From Open to common Property*. Unpublished Master's thesis submitted to the Centre for Environment and Development, University of Natal, Pietermaritzburg, South Africa.

Ashton, P.J. (2002). Avoiding conflicts over Africa's water. *Ambio*, **31**(3): 236-42.

Ashton, P.J. (2007). The role of good governance in sustainable development, in: A.R. Turton, J. Hattingh, G.A. Maree, D.J. Roux, M. Claassen and W.F. Strydom (Eds.), *Governance as a Trialogue: Government-Society-Science in Transition.* (Berlin, Springer-Verlag). Pages 77-100.

Ashton, P.J., Earle, A., Malzbender, D., Moloi, M.B.H., Patrick, M.J. and Turton, A.R. (2006). *A Compilation of All the International Freshwater Agreements Entered into by South Africa with Other States*. Water Research Commission Report No. 1515/1/06. V + 88 pages.

Ashton, P.J. and Ramasar, V. (2002). Water and HIV/AIDS: Some strategic considerations for southern Africa, in: A.R. Turton and R. Henwood (Eds), *Hydropolitics in the Developing World: A Southern African Perspective*. (Pretoria, African Water Issues Research Unit (AWIRU)). Pages 217-235.

Ashton, P.J. and Turton, A.R. (2008, in press). Water and security in sub-Saharan Africa: Emerging concepts and their implications for effective water resource management in the southern African region, in: H.-G. Brauch, J. Grin, C. Mesjasz, H. Krummenacher, N.C. Behera, B. Chourou, U.O. Spring, P.H. Liotta and P. Kameri-Mbote (Eds), *Facing Global Environmental Change: Environmental, Human, Energy, Food, Health and Water Security Concepts – Volume IV*. (Berlin, Springer-Verlag).

Basson, M. S., Van Niekerk, P.H. and Van Rooyen, J.N. (1997). *Overview of Water Resources Availability and Utilization in South Africa.* Report No. P RSA/00/0197. (Pretoria, Department of Water Affairs and Forestry and BKS (Pty) Ltd.).

Bohensky, E.L. and Lynam, T. (2005). Evaluating responses in complex adaptive systems: Insights on water management from the Southern African Millennium Ecosystem Assessment (SAfMA). *Ecology and Society*, **10**(1): 11. Available [online] at: http://www.ecologyandsociety.org/vol10/iss1/art11. (Last accessed on 14 August 2007).

Central Intelligence Agency (CIA) (2007). *The World Factbook: Country Listing*. Available [online] at: http://www.cia.gov/library/publications/the-world-factbook/geos/. (Last accessed on 13 August 2007).

Coopey, J. (2004). Crucial gaps in 'the learning organization': Power, politics and ideology, in: K. Starkey, S. Tempest and A. McKinlay (Eds), *How Organizations Learn Managing the Search for Knowledge.* (London, Thomson Learning). Pages 525-542.

Council for Scientific and Industrial Research (CSIR) (2000). *National Land-cover Database 2000*. (Pretoria, Council for Scientific and Industrial Research).

Couzens, E. and Dent, M. (2006). Finding NEMA: The National Environmental Management Act, the De Hoop Dam, conflict resolution and alternative dispute resolution in environmental disputes. *Potchefstroom Electronic Law Journal*, **3**(6). Available [online] at: http://www.puk.ac.za/fakulteite/regte/per/issue06v3.html. (Last accessed on 14 August 2007).

Davies, B.R. and Wishart, M.J. (2000). River conservation in the countries of the Southern African Development Community (SADC), in: P.J. Boon, B.R. Davies and G.E. Petts (Eds), *Global perspectives on River Conservation: Science, Policy and Practice*. (Chichester, John Wiley & Sons Ltd). Pages 179-204.

Department of Water Affairs and Forestry (DWAF) (1997). *White Paper on a National Water Policy for South Africa.* (Pretoria, Department of Water Affairs and Forestry).

Department of Water Affairs and Forestry (DWAF) (2003a). *Limpopo Water Management Area: Overview of Water Resources Availability and Utilisation*. Report No. P WMA 01/000/00/0203, September 2003. (Pretoria, Department of Water Affairs and Forestry).

Department of Water Affairs and Forestry (DWAF) (2003b). *Luvuvhu and Letaba Water Management Area: Overview of Water Resources Availability and Utilisation*. Report No. P WMA 02/000/00/0203, September 2003. (Pretoria, Department of Water Affairs and Forestry).

Department of Water Affairs and Forestry (DWAF) (2003c). *Crocodile (West) and Marico Water Management Area: Overview of Water Resources Availability and Utilisation*. Report No. P WMA 03/000/00/0203, September 2003. (Pretoria, Department of Water Affairs and Forestry).

Department of Water Affairs and Forestry (DWAF) (2003d). *Olifants Water Management Area: Overview of Water Resources Availability and Utilisation*. Report No. P WMA 04/000/00/0203, September 2003. (Pretoria, Department of Water Affairs and Forestry).

Department of Water Affairs and Forestry (DWAF) (2003e). *Inkomati Water Management Area: Overview of Water Resources Availability and Utilisation*. Report No. P WMA 05/000/00/0203, September 2003. (Pretoria, Department of Water Affairs and Forestry).

Department of Water Affairs and Forestry (DWAF) (2003f). *Usutu - Mhlatuze Water Management Area: Overview of Water Resources Availability and Utilisation*. Report No. P WMA 06/000/00/0203, September 2003. (Pretoria, Department of Water Affairs and Forestry).

Department of Water Affairs and Forestry (DWAF) (2003g). *Upper Vaal Water Management Area: Overview of Water Resources Availability and Utilisation*. Report No. P WMA 08/000/00/0203, September 2003. (Pretoria, Department of Water Affairs and Forestry).

Department of Water Affairs and Forestry (DWAF) (2003h). *Middle Vaal Water Management Area: Overview of Water Resources Availability and Utilisation*. Report No. P WMA 09/000/00/0203, September 2003. (Pretoria, Department of Water Affairs and Forestry).

Department of Water Affairs and Forestry (DWAF) (2003i). *Lower Vaal Water Management Area: Overview of Water Resources Availability and Utilisation*. Report No. P WMA 10/000/00/0203, September 2003. (Pretoria, Department of Water Affairs and Forestry).

Department of Water Affairs and Forestry (DWAF) (2003j). *Upper Orange Water Management Area: Overview of Water Resources Availability and Utilisation.* Report No. P WMA 13/000/00//0203, September 2003. (Pretoria, Department of Water Affairs and Forestry).

Department of Water Affairs and Forestry (DWAF) (2003k). Lower Orange Water Management Area: Overview of Water Resources Availability and Utilisation. Report No. P WMA 14/000/00/0203, September 2003. (Pretoria, Department of Water Affairs and Forestry).

De Wit, M. and Stankiewicz, J. (2006). Changes in surface water supply across Africa with predicted climate change. *Science Express*, 2 March 2006, 10.1126, 9 pages.

Falkenmark, M. (1989). The massive water scarcity now threatening Africa: Why isn't it being addressed? *Ambio*, **18**(2): 112-118.

Folke, C., Hahn, T., Olsson, P. and Norberg, J. (2005). Adaptive governance of social-ecological systems. *Annual Review of Environmental Resources*, **30**: 441-473.

Giddens, A. (1979). *Central Problems in Social Theory.* (London, Macmillan).

Hara, M.M., Donda, S.J. and Njaya, F.J. (2002). Lessons from Malawi's experience with fisheries co-management initiatives, in: K. Geheb and M.T. Sarch (Eds.), *Africa's Inland Fisheries: The Management Challenge.* (Kampala, Fountain Publishers).

Heeg, J. and Breen, C.M. (1994). Resolution of conflicting values on the Pongolo River Floodplain (South Africa), in: B. Patten et al. (Eds), *Wetlands and Shallow Continental Water Bodies - Volume 2* B. (The Hague: SBP Publishing). Pages 303-359.

Heyns, P.S.v.H. (2002). The inter-basin transfer of water between countries within the Southern African Development Community (SADC): A developmental challenge of the future, in: A.R. Turton and R. Henwood (Eds), *Hydropolitics in the Developing World: A Southern African Perspective.* (Pretoria, African Water Issues Research Unit and International Water Management Institute). Pages 157-176.

Kamminga, E. and Schuringa, M.W. (2005). *HIV/AIDS and Water, Sanitation and Hygiene*. (Delft, IRC International Water and Sanitation Centre). Available [online] at: http://www.irc.nl. (Last accessed on 10 August 2007).

Langridge, R., Christian-Smith, J. and Lohse, K.A. (2006). Access and resilience: Analyzing the construction of social resilience to the threat of water scarcity. *Ecology and Society*, **11**(2): 18. Available [online] at: http://www.ecologyandsociety.org/vol11/iss2/art. (Last accessed on 24 November 2007).

Mohamed, A.E. (2003). Joint development and cooperation in international water resources, in: M. Nakayama (Ed.), *International Waters in Southern Africa*. (Tokyo, United Nations University Press). Pages 209-248.

Nel, J.L., Roux, D.J., Maree, G.A., Kleynhans, C.J., Moolman, J., Reyers, B., Rouget, M., Cowling, R.M. (2007). Rivers in peril inside and outside protected areas: A systematic approach to conservation assessment of river ecosystems. *Diversity and Distributions*, **13**: 341-352.

Nkhata, A.B., Breen, C.M. and Freimund, W.A. (2007). Resilient social relationships and collaboration in the management of social-ecological systems. *Ecology and Society*, **12**. Available [online] at: http://www.ecologyandsociety.org/vol12/iss6/art. (Last accessed on 24 November 2007).

O'Keeffe, J.H. (1989). Conserving rivers in southern Africa. *Biological Conservation,* **49**: 255-274.

Pallett, J. (1997). *Sharing Water in Southern Africa.* (Windhoek, Desert Research Foundation of Namibia).

Postel, S. and Richter, B. (2003). *Rivers for Life: Managing Water for People and Nature*. (Washington D.C., Island Press). 253 pp.

Rascher, J., Ashton, P.J. and Turton, A.R. (2008, in press). The strategic role of water in alleviating the human tragedy associated with HIV/AIDS in Africa, in: A.

Biswas and C, Tortajada (Eds), *Water Management in 2020 and Beyond*. (Zaragosa, International Water Institute).

Republic of South Africa (1998). *National Water Act (Act No. 36 of 1998). (*Pretoria, Government of the Republic of South Africa).

Roux, D.J., Nel, J.L., MacKay, H.M. and Ashton, P.J. (2006). *Cross-sector Policy Objectives for Conserving South Africa's Inland Water Biodiversity*. WRC Report No TT 276/06. (Pretoria, Water Research Commission).

SADC (Southern African Development Community) (1998). *Regional Strategic Action Plan (RSAP) for Integrated Water Resources Development and Management in the SADC Countries (1999-2004). Summary Report.* (Maseru, SADC Water Sector Co-ordinating Unit).

SADC (Southern African Development Community) (2001). *Revised Protocol on Shared Watercourse Systems in the Southern African Development Community (SADC) Region*, Windhoek: Southern African Development Community, available [online] at: www.sadc.int. (Last accessed on 15 July 2007).

Smakhtin, V. (2001). Low flow hydrology: a review. *Journal of Hydrology*, **240**: 147-186.

Statistics South Africa (STATS-SA) (2007). *South African Population Statistics: Census 2001*. Available [online] at: http://www.statssa.gov.za/census01/html. (Last accessed on 13 August 2007).

Turton, A.R. (2003). An overview of the hydropolitical dynamics of the Orange River basin, in: M. Nakayama (Ed.), *International Waters in Southern Africa.* (Tokyo, United Nations University Press). Pages 136-163.

Turton, A.R. and Ashton, P.J. (2007, in press). Basin closure and issues of scale: The Southern African Hydropolitical Complex, in: *International Journal of Water Resources Development*, Special Edition "Basin Closure", M Falkenmark (Ed.).

Turton, A.R., Earle, A., Malzbender, D. and Ashton, P.J. (2006). Hydropolitical vulnerability and resilience along Africa's international waters. Chapter 2, in: A.T. Wolf (Ed.), *Hydropolitical Resilience and Vulnerability along International Waters*. (Nairobi, United Nations Environment Program). Report No. UNEP/DEW/0672/NA. Pages 19-67.

UNAIDS (2006). *Aids Epidemic Update. Country Profiles*. (Geneva, UNAIDS). Available [online] at: http://www/unaids/org. (Last accessed on 19 August 2007).

UN Millennium Project (2005). Lack of access to water and sanitation hampers efforts to reduce poverty in developing countries. Available [online] at: http://www.unmillenniumproject.org/press/tf7_e.htm.

Van der Leeuw, S.E. and Aschan-Leygonie, C. (2000). A long-term perspective on resilience in socio-natural systems. Paper presented at the workshop on *System Shocks – System Resilience*, held in Abisko, Sweden, May 22-26, 2000. Available [online] at: http://www.santafe.edu/research/publications/workingpapers/01-08-042.pdf. (Last accessed on 17 September 2007).

Van Wyk, E., Breen, C.M., Roux, K. H. Rogers, Sherwill, T. and B. W. van Wilgen, B.W. (2006). The ecological reserve: Towards a common understanding for river management in South Africa. *Water SA,* **32**(3): 403-409.

Walker, B.H., Holling, C.S., Carpenter, S.R. and Kinzig, A. (2004). Resilience, adaptability and transformability in social-ecological systems. *Ecology and Society*, **9**(2): 5. Available [online] at: http://www.ecologyandsociety.org/vol9/iss2/art. (Last accessed on 4 September 2007).

Walker, B.H. and Salt, D. (2006). *Resilience Thinking: Sustaining Ecosystems and People in a Changing World*. (Washington, D.C., Island Press).

WCD (World Commission on Dams) (2000). *Dams and Development: A New Framework for Decision-Making.* (London, Earthscan).